Title: Preventive action of organosilicon treatments against disfigurement of wood under laboratory and outdoor conditions

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Scientific relevance

Several authors state that organosilicons have potential to be used for treatment of wood under use class three applications, whether or not as part of more complex formulations. Most studies focus mainly on durability and stability of the obtained wood product, although also other parameters are important, especially when for example cladding is the final product. Moreover often only laboratory experiments are performed, while it is already demonstrated that real life exposure studies are indispensable to evaluate the treated wood properly. This research therefore examines the colour and fungal disfigurement of treated wood both under laboratory and outdoor conditions. Organosilicon treatment of wood is no real wood preservation, nor wood modification, nor the application of a surface coating. This study therefore tries to gain new insights in how to properly evaluate blue stain attack of organosilicon treated wood under laboratory conditions. Furthermore colour and fungal disfigurement of treated wood exposed outside are investigated. This research can therefore be regarded as a completion of existing work on organosilicon treated wood and tries to fill some of the gaps concerning the general appearance of organosilicon treated wood exposed outdoors.

1. Introduction

Wood is a building material that, due to its diversity, can be applied in a broad range of applications. Depending on the type of application specific demands of the wood are required ranging from architectural or technical specifications to customer-driven demands. For most customers appearance is the decisive factor in their choice between wood and synthetic, metal or mineral alternatives in favour of wood. Measuring customer preferences is however not straightforward. For outdoor wood applications fungal disfigurement and colour are two main factors determining the appearance (Salcă and Fotin 2007).

Organosilicons have proven effectiveness as hydrophobing agents in for example the textile, paper and building industry (Rochow 1987; Hager 1995; Lukowsky and Peek 1997; Roos et al. 2008). Their suitability to protect wood was suggested and aspects like durability, moisture stability etc. have been investigated (Hager 1995; Tshabalala et al. 2003; Mai and Militz 2004; De Vetter and Van Acker 2005). However, most studies found that treatment of wood with organosilicons can only lead to a significant improvement of the investigated property when applied at (very) high concentrations (Hill et al. 2004; Weigenand et al. 2007; De Vetter et al. 2009a). Treatments at lower, economically feasible concentrations lead to only modest improvements of the wood properties (Goethals and Stevens 1994; Mai et al. 2005; De Vetter et al. 2009b). Nevertheless, most of these authors conclude that wood treatment with an organosilicon may contribute significantly to prolong the service life of the wooden element when applied as part of a more complex (preservative containing) formulation for use class three applications like exterior cladding (Mai et al. 2005; Donath et al. 2006; De Vetter et al. 2009a; b).

It was therefore the purpose of this study to evaluate both fungal disfigurement and colour change of organosilicon treated wood under use class three applications (EN 335-1 2006). Therefore a broad range of different organosilicons was used as test group. For a subgroup of specimens organosilicons were combined with biocides. Depending on the test set-up they were applied using dipping or vacuum impregnation. Both laboratory and outdoor field tests were performed investigating the performance of the applied systems under the specific circumstances.

2. Materials and methods

2.1. Products

Both organosilicon solutions as such, as well as combinations of an organosilicon with a biocide were used to treat the specimens. The organosilicons cover both solvent-based and water-based systems (De Vetter et al. 2009a; b). Basically two 100 % w/w active (conc_active_ingredient) solvent-based alkoxysilanes were tested; the first product contained only N-octyltriethoxysilane (n-OTES) and the second was a combination of n-OTES and methyltrimethoxysilane (MTM). Furthermore a 50 % w/w active emulsion of methoxy-terminated dimethylphenylsiloxane (DMS) and n-OTES (DMS/n-OTES 1) and a 100 % w/w active micro-emulsion of polydimethylsiloxane (PDMS) and triethoxysilane (TES) were included. Finally also a 40 % w/w active mixture of DMS and n-OTES (DMS:n-OTES 2) and a 60 % w/w active macro-emulsion of PDMS were used. All these products were developed at the laboratories of Dow Corning Corporation (Belgium), except for the 100 % PDMS/TES which was obtained from Wacker-Chemie GmbH (Germany). The solvent-based and water-based systems were diluted up to 5 % w/w (ai_conc) with isopropylalcohol and water, respectively.

The same combinations of organosilicons and biocides as used in De Vetter et al. (2009b) were applied. Briefly, a 5 % solution of the DMS/n-OTES 2 was combined with (1) 0.3 % 3-iodo-2-propynyl-butyl carbamate (IPBC); (2) 0.3 % IPBC in combination with 0.6 % (±)-(cis+trans)-1-(2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl-methyl)-1H-1,2,4-triazole (propiconazole) and (3) 2 % 3-(trimethoxysilyl)propyldimethyloctadecyl ammonium chloride (Si-Quat). As a solvent-based counterpart 5 % w/w MTM/n-OTES was combined with (1) 0.3 % IPBC and (2) 0.3 % IPBC in combination with 0.6 % propiconazole. Thirdly 10 % MTM/n-OTES was combined with 1 % Si-Quat. Summarizing six organosilicons and six combinations of an organosilicon and a biocide were applied. In addition to the treated specimens, untreated Scots pine sapwood reference specimens were included in the tests as well. Moreover, in the natural weathering test untreated heartwood of Scots pine, Douglasfir (*Pseudotsuga* spp.) and larch (*Larix decidua*), having the same dimensions as the Scots pine specimens, were added to the pine sapwood references.

2.2. Laboratory experiments

Both fungal disfigurement and colour change were evaluated on laboratory and semi-industrial scale. Therefore pre-conditioned (12 % moisture content) straight grained Scots pine (*Pinus sylvestris* L.) sapwood was used. For the laboratory experiments, the wood was sawn to 320×40×10 mm, end-grain cross sections were sealed twice with a 2-component water impermeable polyurethane system and dipped for a few seconds into the treating solutions into four replicates. The specimens were weighed before and after dipping, allowing calculation of the product and active ingredient retention of organosilicon and biocide (Eq. 1 and 2). The specimens were placed into an Atlas UV2000 and artificially weathered during six weeks using a test cycle as described in the new draft version of EN 152. Prior to weathering and in between two subsequent cycles, consisting of a wetter and dryer subcycle, the colour was determined (see further).

$$\mathrm{Pr}oduct_{retention}(g/m^2) = \frac{m_{after\_impr}(g) - m_{before\_impr}(g)}{area(cm^2)} \times \frac{ai\_conc(\%) \times 10.000}{conc\_active\_ingredient(\%)} \quad (1)$$

$$Active\_ingredient_{retention}(g/m^2) = \frac{m_{after\_impr}(g) - m_{before\_impr}(g)}{area(cm^2)} \times ai\_conc(\%) \times 10.000 \quad (2)$$

Afterwards the specimens were conditioned (at 20 °C and 65 % RH) and out of every weathered specimen four smaller specimens were sawn for blue stain evaluation. Two had the dimensions of standard EN 152 specimens (90×40×10 mm, 2003), while two smaller specimens were sawn according to the recommendations for the reverse EN152 method (50×40×10 mm, Van den Bulcke et al. 2006). The first method is the so-called wood preservatives approach, while the latter is the wood coating approach.

The EN 152 specimens were planed at the non-weathered side removing the applied organosilicon (and biocide) leading to an untreated surface, easy accessible for fungi. In contrast, half of the reverse specimens were sealed on all but the weathered side, forcing the fungi to grow through the weathered organosilicon (and biocidal) layer. The other reverse specimens were sealed on all but the non-weathered side, this time preventing fungal growth from any side, except via the non-weathered organosilicon (and biocidal) layer. The sealant was a translucent 2-component polyurethane system doped with dichlofluanid to prevent staining. Resuming the sawing pattern lead to eight different standard EN152-specimens, four reverse weathered and four reverse non-weathered specimens per treatment, each exposed in a single jar to blue stain attack. Besides these treated specimens four artificially

weathered as well as non-weathered untreated Scots pine sapwood specimens were included in the test as reference specimens.

A spore suspension of *Aureobasidium pullulans* (de Barry) Arnaud P268 and *Sydowia polyspora* (Corda) V. Höhn S 231 was prepared as explained in Van den Bulcke et al. (2006). After the specimens were γ-sterilised (1.5 Mrad), they were shortly dipped in the spore suspension and put on a vermiculite substrate after which another 15 ml of spore suspension was poured over the specimens. After six weeks incubation at 22 °C and 70 % RH a visual, exterior assessment of the blue stain specimens, excluding the edges, was performed according to the rating scale as defined in EN 152: 0: not blue stained; 1: insignificantly blue stained; 2: blue stained; 3: strongly blue stained. These classes were further subdivided using 0.5 increments, as proposed by Van den Bulcke et al. (2006) to have more precise ratings. For the interior assessment the EN 152 specimens were cut parallel to the end faces at 30 mm from each end (EN 152), while the reverse specimens were sawn in half. The rating scale as proposed by Van Acker et al. (1998) was used for the evaluation: 0: no blue stain found; 1: few spots of blue stain; 2: small blue stained areas; 3: specimen is partly blue stained, but there are still areas free of blue stain; 4: the major part of the specimen is blue stained; 5: cross-cut of the specimen is completely blue stained.

2.3. Outdoor performance testing

For the semi-industrial scale or outdoor experiments Scots pine sapwood specimens of 375×100×20 mm were used, which were also sealed at both end-grain cross sections in the same manner as for the laboratory scale tests. Half of these specimens were dipped into the treating solutions, while the other half was vacuum impregnated in the same solution using a pressure of 5 bars for 45 minutes. After releasing the pressure the specimens stayed submerged for another 15 minutes at atmospheric pressure and were finally removed from the tank and allowed to drip for 15 minutes. Four replicates per treating solution and treatment procedure were used. Mass of each specimen was measured prior to and after treatment allowing calculation of the organosilicon (and biocide) product retention (Eq. 3) as well as weight percent gain (WPG, Eq. 4) for the impregnated specimens. The treated specimens were then dried at 60 °C until they reached constant mass.

$$\mathrm{Pr}oduct_{retention}(kg/m^3) = \frac{m_{after\_impr}(g) - m_{before\_impr}(g)}{volume(cm^3)} \times \frac{ai\_conc(\%) \times 1.000}{conc\_active\_ingredient(\%)} \quad (3)$$

$$WPG(\%) = \frac{m_{after\_impr} - m_{before\_impr}}{m_{after\_impr}} \times ai\_conc\ (\%) \quad (4)$$

After conditioning at 20 °C and 65 % RH the specimens were weighed again, inspected visually and mounted outdoors on a rack having an inclination of 45° and facing south-southwest (EN 927-3 1996). The rack was located at the outdoor weathering site of the Laboratory of Wood Technology in Belgium. The specimens were not inoculated with any spore suspension.

Donath (2004) already demonstrated that visually evaluating the back, and thus non-weathered side (facing north) of such outdoor exposure specimens reflects well the resistance against moulds of a product. Therefore, for the evaluation of fungal disfigurement the specimens were visited every season and evaluated external on their back for fungal disfigurement. Although most fungi were moulds, other fungi were not disregarded. The

following rating scale was drawn up and used to classify each specimen: 0: no fungal disfigurement; 1: small spots of fungi are detected; 2: fungi in a small band at the upper part of the specimen; 3: fungi scattered in broader bands over the surface of the specimen; 4: specimen' surface completely overgrown with fungi.

For the colour evaluation the specimens were yearly removed from the rack and conditioned for seven days at 20 °C and 65 % RH. Afterwards the colour was measured at the front side, facing south-south west.

2.4. Colour evaluation

For the colour evaluation use was made of a Spectrophotometer Konica Minolta CM-2600d and the obtained colour was expressed as a CIE*Lab-value. Per specimen five colour measurements were performed, which were averaged to a mean value of L*, a* and b*. L* represents the lightness of the sample and ranges from black (0 %) to white (100 %) while a* and b* are chromaticity values representing the red to green and yellow to blue colour, respectively. It is plausible to assume that for a customer once he has chosen for a certain wood product, not the colour as such but the colour change over time is of major importance in the appreciation of the wood product. Therefore preference was given to evaluate the colour difference dE of each specimen and this considering both the application of a treatment product as well as the time of weathering. Therefore dE was calculated as the colour difference between each specimen at a certain time t compared to the colour of untreated and non-weathered Scots pine sapwood (Eq. 6). The reference values for L*, a* and b* were the average values of all untreated and non-weathered Scots pine sapwood specimens included in the artificial weathering test.

$$dE = \sqrt{(L^*_t - L^*_{ref})^2 + (b^*_t - b^*_{ref})^2 + (a^*_t - a^*_{ref})^2} \quad (6)$$

2.5. Statistics

Since for fungal disfigurement only a limited number of replicates was used and the rating is nonlinear anyhow the median value was preferred over the average value as to minimise the impact of outliers. Furthermore it is not the purpose to evaluate products but to retrieve information whether organosilicons as a group can decrease fungal disfigurement. Therefore the obtained rating values were not interpreted as such, but used to make clusters of products performing the same as, better than or much better than untreated Scots pine sapwood. To lower the impact of outliers the Partitioning Around Mediods (PAM) cluster analysis was preferred. The analysis was performed for each testing protocol separately (EN152, reverse weathered and reverse non-weathered) and for combinations of tests. The number of clusters to retain was determined using scree analyses. Prior to acceptance of each clustering it was checked whether they could explain at least 80 % of the variability between the treatments. The clusters fulfilling this requirement were then compared with each other.

For the colour evaluation of both tests, using artificial or natural weathering, first a two-way analysis of variance (ANOVA) with fixed factors was performed. The dependent variable was the colour difference dE of each specimen compared to untreated Scots pine sapwood prior to weathering and the independent variables were treatment and time. If significant interaction between the independent factors was found, meaning that dE depends on the combination of treatment and time, the two-way ANOVA could not be further interpreted. Therefore a one-way ANOVA was performed with dE as dependent variable and a new factor Group as independent variable. Group contains all possible combinations of treatment

and time. Consecutive post-hoc analyses using Scheffé-tests revealed which groups differed significantly from each other.

3. Results

3.1. Product retention

Table 1 gives a schematic overview of the product compositions, product codes, product retentions, active ingredient retentions and WPGs for the different test set-ups.

Table 1

3.2. Laboratory experiments

3.2.1 Fungal evaluation

Clustering the EN 152 data was not possible for the exterior evaluation data and was not satisfactory for the interior EN 152 evaluation data. Nearly all specimens were completely blue stained and had therefore the same exterior rating (Fig. 1), while less than 80 % of the variability of the interior evaluation could be explained by the treatment (Fig. 2). Although slight differences in fungal disfigurement were observed, they could not be extracted from the analysis. Furthermore the biocides used have proven anti blue stain effectiveness (Isquith et al. 1972) at the concentrations applied (Valcke 1989). Therefore it seems that the wood preservatives approach is not fully suitable for evaluating organosilicon treated wood. Indeed, the coating approach as defined by Van den Bulcke (2006) is more appropriate for evaluating the blue stain resistance of organosilicon treated wood. For all reverse data, whether exterior or interior, weathered or not, three clusters were obtained. Untreated Scots pine sapwood and most treatments comprising only an organosilicon belong to the same cluster, the one of worst performing treatments. The cluster with the best performing treatments contains those treatments where IPBC with propiconazole is involved. The other biocide containing treatments most often belong to the intermediate cluster. However, in case of interior evaluation these treatments might also belong to the best performing cluster.

Figure 1
Figure 2

3.2.2 Colour evaluation

The average L*, a* and b* values of untreated and non-weathered Scots pine sapwood specimens were 82.7, 4.6 and 24.3 respectively and were used both in the artificial and natural weathering tests to calculate the colour difference dE. For dE significant interaction ($p < 0.05$ for both artificially and naturally weathered wood) between treatment and time was found. The consecutive one-way ANOVA revealed significant differences between the groups (both $p < 0.05$), leading to Scheffé-tests to discover which groups differ significantly from each other. The mean colour difference dE and the corresponding standard deviation are presented in function of the treatment in Fig. 3 for artificially weathered wood. The figure shows that dipping of untreated Scots pine sapwood in solutions containing DMS/n-OTES 1 or MTM/n-OTES + Si-Quat induce a significant colour difference compared to untreated Scots pine sapwood. The other treatments do not lead to a significant colour difference. Furthermore the figure shows that, as expected, colour difference of untreated Scots pine sapwood increases with time. However, there is no significant colour difference between specimens exposed for the same time period. After the third weathering cycle dE increases again, leading to significant colour differences compared to the previous cycle (cycle 2). It can therefore be summarized that among specimens exposed for the same exposure period no major colour differences are present. After one weathering cycle only a small number of

treatments have a significant different dE compared to the non-weathered wood, whereas this number increases after two cycles and is valid for all treatments after three cycles.

Figure 3

Although the total colour difference is of major importance to consumers, dE does not indicate the direction of colour change. Therefore, a closer look was taken on its components L*, a* and b* (data not presented). None of these values on its own was significantly different from each other or untreated Scots pine sapwood, indicating treatment did not influence the colour parameters. The weathering procedure itself however did influence the colour change, making all specimens discolour in the same manner. The specimens became brighter and less red until the second weathering cycle after which they became darker and redder, while yellowing continued. Summarizing it can be said that dipping of Scots pine sapwood into an organosilicon solution does not have a significant effect on any of the colour components, while artificial weathering does have a significant effect on the colour.

3.3. Outdoor performance testing

3.3.1 Fungal evaluation

Also for the natural weathering test clustering into three groups was the best option (data not shown). Regardless the exposure period untreated Scots pine sapwood and half of the dipping treatments in organosilicons are grouped as worst performing. The other half of the in organosilicon dipped treatments, along with impregnations with organosilicons and dipping in solutions containing Si-Quat are clustered in the intermediate performing group. To the best performing group belong, besides all reference wood species, impregnations containing biocides IPBC and IPBC + propiconazole. The remaining treatments not yet mentioned, are impregnations with an organosilicon and the biocide Si-Quat and dipping including IPBC and IPBC + propiconazole. After one year natural weathering they belong to the best group, while they lose effectiveness over time resulting in a shift towards the medium group after two (and three) years weathering.

3.3.2 Colour evaluation

For the colour evaluation of naturally weathered wood, only Scots pine sapwood was evaluated, whether treated or not. The colour difference dE seems far more complicated (Fig. 4 and 5) and doesn't change so uniformly as for artificially weathered specimens. Since the colour data prior to weathering are missing, no conclusions concerning the influence of each treatment on the colour can be made. Although the standard deviations are much greater than for artificially weathered specimens, after one year natural weathering it is clear that there is no significant difference in dE value of dipped specimens and untreated Scots pine sapwood, except when the biocides IPBC or IPBC + propiconazole are included (Fig. 4). However, these differences fade away with longer exposure time. Specimens impregnated with DMS/n-OTES 1 (Fig. 5) have the largest colour difference compared to untreated and non-weathered Scots pine sapwood, while specimens impregnated with combinations of an organosilicon with IPBC or IPBC + propiconazole have the smallest colour difference. This means that the colour of these last treatments resemble the longest to untreated and non-weathered Scots pine sapwood. After two and three years the colour of these specimens approach that of untreated and weathered Scots pine sapwood. Generally, dE differences become comparable for all treatments after two years weathering and increases slightly for all specimens when weathering is continued for another year

Figure 4
Figure 5

Trying to retrieve which colour component is most influenced, L*, a* and b* values were compared with each other (data nor presented). The data can be separated into a group containing untreated Scots pine sapwood and Scots pine treated with solely an organosilicon and a group containing specimens treated with a combination of an organosilicon and a biocide. While the L* value does not significantly differ within the first group, specimens belonging to the second group are much brighter, especially when treated with IPBC or IPBC + propiconazole. The trends in redness and yellowness are comparable for all specimens in that way that all values are comparable to each other regardless the exposure period, except for impregnation treatments with DMS/n-OTES 1 and impregnations involving IPBC and IPBC + propiconazole, which have slightly higher a* and b* values after the first exposure year. It can therefore be concluded that mainly the L* value is responsible for the bigger variation in colour among all specimens, whereas also a* and b* contribute to the colour difference treatments with DMS/n-OTES 1 and the biocides IPBC and IPBC + propiconazole have compared to all other treatments and untreated Scots pine sapwood.

4. Discussion

4.1 Fungal evaluation

Although both laboratory and semi-industrial experiments evaluate fungal disfigurement, they cannot just be compared with each other. In the first experiment blue stains are the fungi leading to the disfigurement, while in the second experiment multiple factors influence the disfigurement, i.e. fungi (mainly moulds) and dirt.

Nevertheless are the poor results of organosilicons as preventive agents of blue stain and mould supported by the results found by Weigenand et al. (2006) and Ritschkoff et al. (2003). While better performance of outdoor specimens treated with a biocide containing solution is not astonishing, better performance of with organosilicons impregnated specimens is remarkable. Knowing that the presence of mould fungi indicates the availability of nutrients at the wood surface (Block 1953), it can be assumed that the organosilicons, when impregnated, protect the wood surface from fast release of nutrients. This, on its turn, might be attributed to the influence organosilicons have on the moisture dynamics of the treated wood (Tshabalala et al. 2003; Donath et al. 2006).

The diminishing effect of dipped specimens can probably be ascribed to weakening and subsequent degradation of the wood below the surface due to weathering (Banks and Evans 1984), leading to a reduced effect of the superficially applied organosilicon. It can be stated that, except for the organosilicon plus biocide dipped specimens, the clustering of visual ratings after one year weathering already gives a good idea of the clustering after three years exposure.

4.2 Colour evaluation

Artificial weathering is supposed to imitate natural weathering in a fast and uniform way, trying to obtain reliable results which are easily reproducible on a standardized method. Up to now no such method uniting all these parameters has been found. Therefore care must be taken when comparing artificial and natural weathering with each other.

Concerning the initial darkening and subsequent lightening of the wood during artificial weathering, this can be explained because UV light (340 nm) induces the formation of free radicals and lignin is broken down while absorbing the UV light, in that way darkening the wood However, afterwards reaction products are leached out by which the wood becomes brighter again (Donath et al. 2007). Lightening of naturally exposed specimens however,

seems to depend on some extra parameters, since the biocide presence influences the lightness of the treated wood considerably. Two main reasons are probably the presence of dirt and discolouring fungi at the specimens' surface. Since the specimens were washed with clear lukewarm water prior to colour measurements, it is assumed that the effect of dirt is minimised. Basically it is assumed that due to the presence of a biocide the wood surface is not so vulnerable to colonisation of discolouring fungi, leading to less darkening of the wood. The fact that also the biocide treated specimens become darker with time support this hypothesis, as it might be expected that the biocide becomes less effective due to weathering. This is further supported because darkening after one year exposure is far more distinct for dipped specimens than for impregnated specimens

The redness and yellowness values are much lower for the naturally weathered specimens after one year exposure than for the artificially weathered specimens after six weeks. Moreover they reach for nearly all treatments a constant value, supporting that most discolouration happens shortly after exposure. Certain impregnated specimens have slightly higher a* and b* values after one year exposure, indicating they are somehow protected from fast degradation, leaching or evaporation of wood components (Sjöström 1992; Grekin 2007; Salcă and Fotin 2007), or from other processes induced by UV radiation (Hon 1979) which usually lead to colour change. This effect is however only temporarily and minor compared to the impact of the L* value on the total colour difference.

4.3. General appearance

The general appearance of weathered specimens is greatly influenced by fungal disfigurement and UV induced colour variations. Because in the laboratory experiment both parameters were investigated separately from each other, it is not straightforward to give an impression of the general appearance of the specimens. Nevertheless do both the fungal and colour evaluation suggest that only when a biocide is involved in the treatment process, significant different appearance of the specimens can be expected. The natural weathering test is far more interesting, since disfigurement of both kinds was happening simultaneously on the same specimens. The test showed that the general appearance depended on several factors. The presence of a biocide influenced both parameters positively, leading to a brighter and more uniformly discoloured specimen compared to untreated Scots pine sapwood. Slight differences in colour and fungal disfigurement were present between specimens treated with different organosilicons. Regardless the composition of the treatment solution, both discolouration and fungal disfigurement were less pronounced for impregnated specimens compared to their dipped counterparts.

5. Conclusion

Treatment of wood with an organosilicon cannot be regarded as a form of wood modification in a strict sense, wood preservation or the application of a coating. Therefore it is not self-evident to find a method for evaluating the performance against blue staining of organosilicon treated wood whether or not in combination with a biocide. This study showed that the coating approach is more suited than the wood preservatives approach, since it is more discriminating. Secondly this research proved that under laboratory conditions an organosilicon as such is not able to protect the wood sufficiently, but combinations with biocides have good perspectives. However, outdoors the organosilicons show better resistance against fungal disfigurement than untreated wood. Obviously, the addition of a biocide enhances this effect. The discrepancy between laboratory testing and outdoor performance testing is stressed. While the former was not able to distinguish products with good perspectives from those with fewer perspectives, real outdoor performance proved significant differences are present between specimens depending on the treatment product

and application technique and was more hopeful for the potential of organosilicons as part of formulations designed to protect wood surfaces under use class three conditions.

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Figure captions

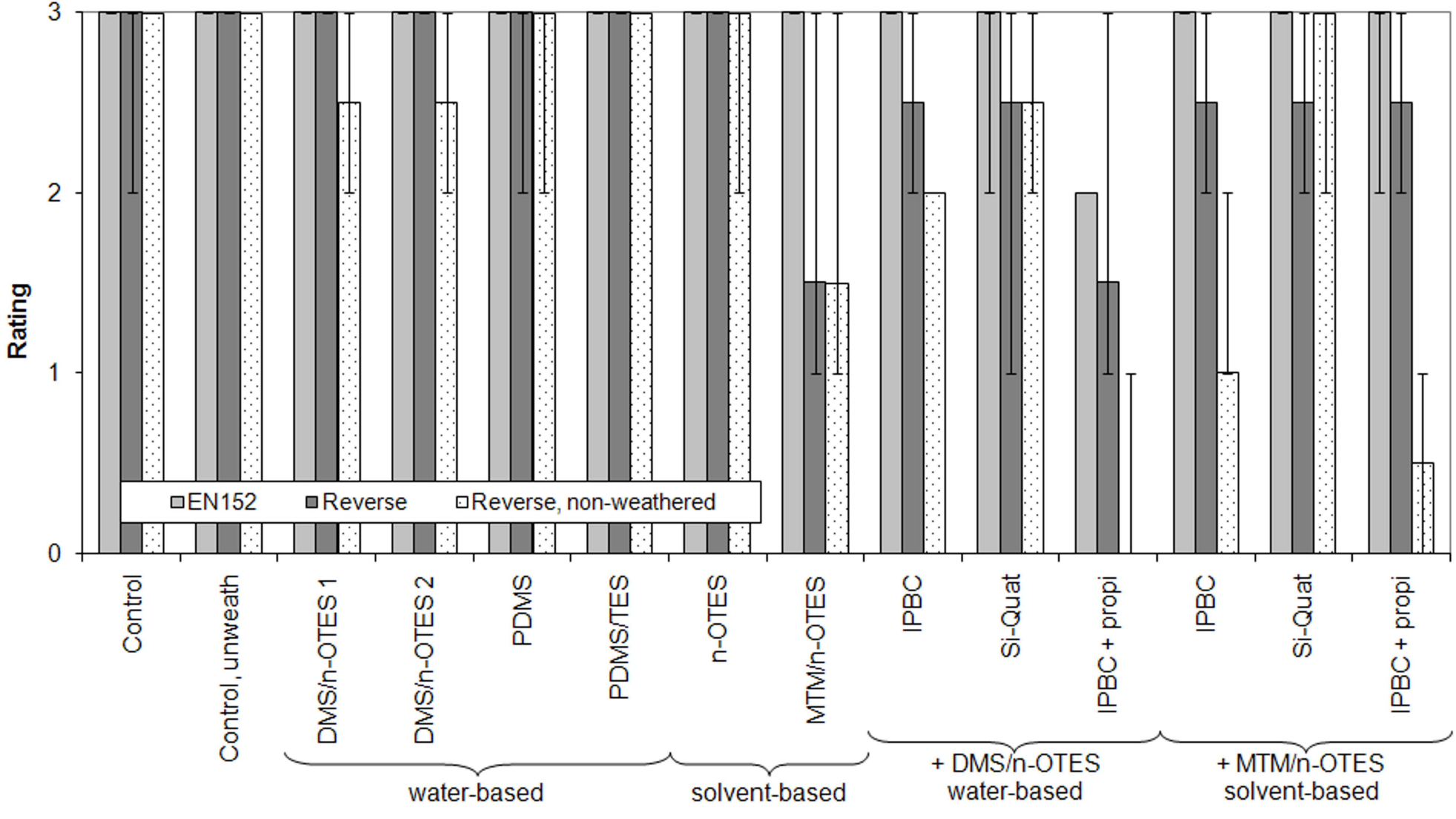
Figure 1: Median, minimum and maximum exterior rating (0-3) of specimens dipped into an organosilicon (and biocidal) solution, weathered during six weeks in an Atlas UV2000 and subsequently blue stained according to (1) the standard EN 152 method, (2) EN 152 reverse method or (3) EN 152 reverse method, but at the non-weathered side.

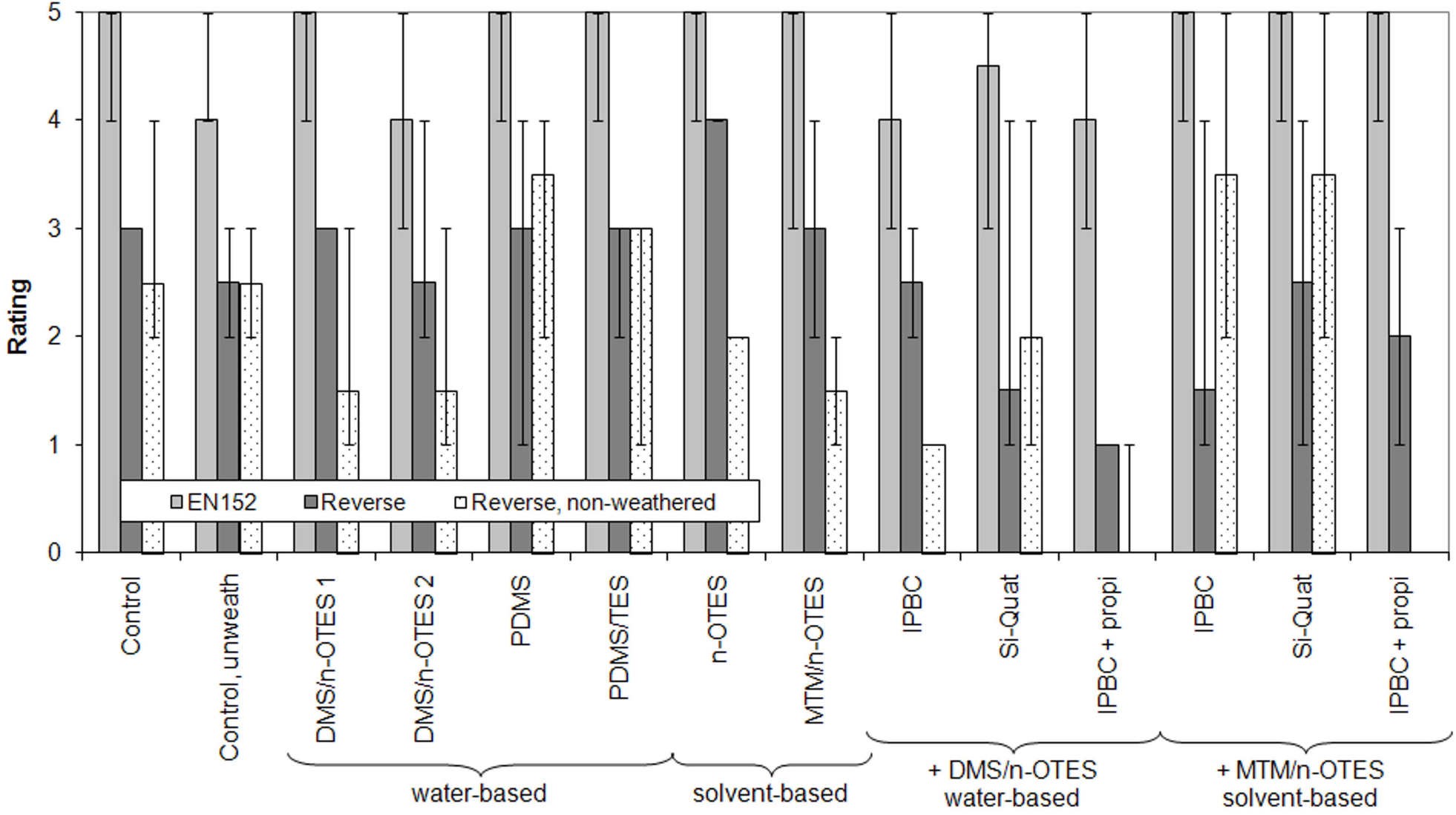
Figure 2: Median, minimum and maximum interior rating (0-5) of specimens dipped into an organosilicon (and biocidal) solution, weathered during six weeks in an Atlas UV2000 and subsequently blue stained according to (1) the standard EN 152 method, (2) EN 152 reverse method or (3) EN 152 reverse method, but at the non-weathered side.

Figure 3: Averages and standard deviations of the colour parameter dE for untreated Scots pine sapwood (Control) and Scots pine sapwood dipped into an organosilicon (and biocidal) solution. The diamond symbols represent the values prior to weathering while the circle, square and triangl symbols represent the values after one, two and three consecutive artificial weathering cycles, respectively.

Figure 4: Averages and standard deviations of the colour parameter dE for untreated Scots pine sapwood (Control) and Scots pine sapwood dipped into an organosilicon (and biocidal) solution. The circle, square and triangle symbols represent the values after respectively one, two and three years natural weathering at the outdoor exposure site of the Ghent University, Belgium.

Figure 5: Averages and standard deviations of the colour parameter dE for untreated Scots pine sapwood (Z) and Scots pine sapwood impregnated with an organosilicon (and biocidal) solution. The circle, square and triangle symbols represent the values after respectively one, two and three years natural weathering at the outdoor exposure site of the Ghent University, Belgium.


Rating
3
2
1
0
EN152
Reverse
Reverse, non-weathered
Control
Control, unweath
DMS/n-OTES 1
DMS/n-OTES 2
PDMS
PDMS/TES
n-OTES
MTM/n-OTES
IPBC
Si-Quat
IPBC + propi
IPBC
Si-Quat
IPBC + propi
water-based
solvent-based
+ DMS/n-OTES
water-based
+ MTM/n-OTES
solvent-based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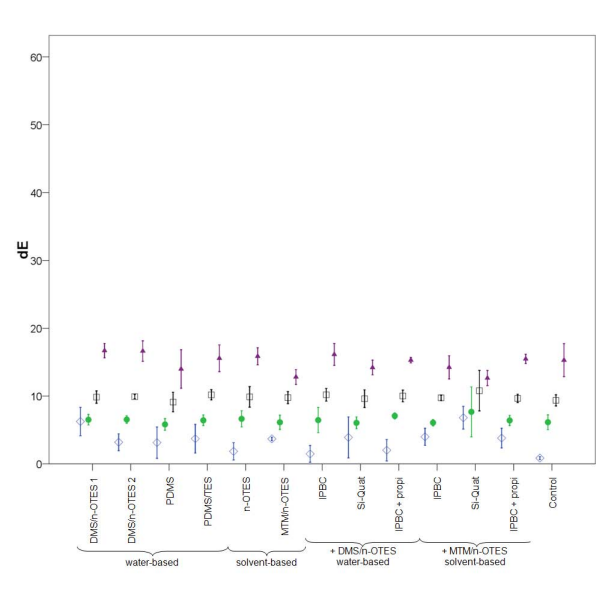
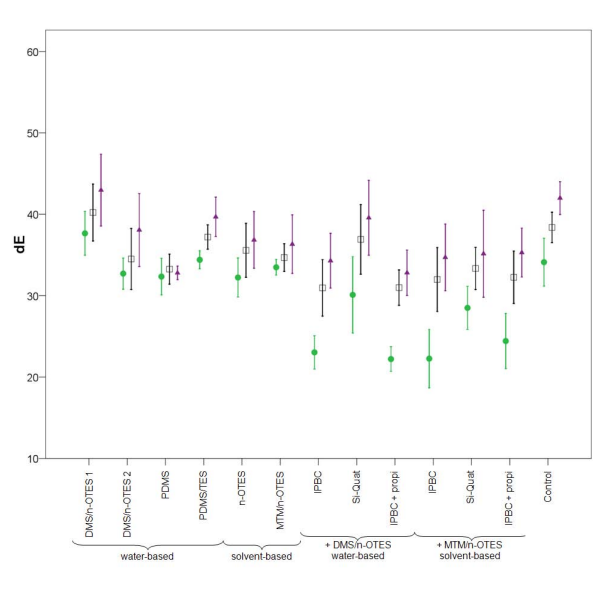
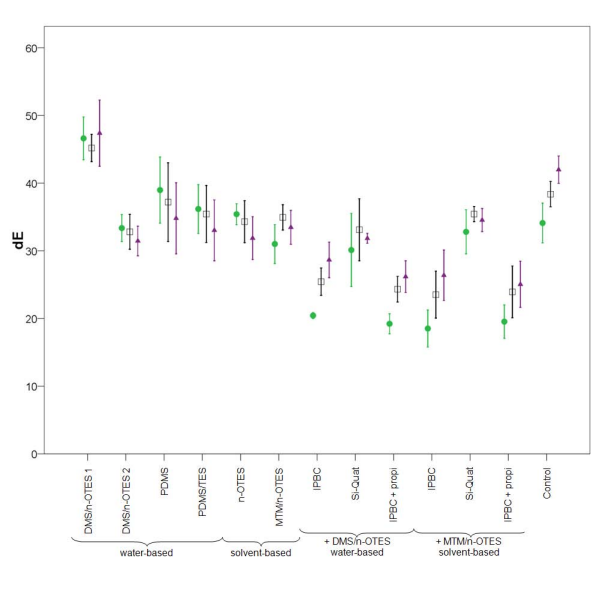
4
3
2
1
0
EN152
Reverse
Reverse, non-weathered
Control
Control, unweath
DMS/n-OTES 1
DMS/n-OTES 2
PDMS
PDMS/TES
n-OTES
MTM/n-OTES
IPBC
Si-Quat
IPBC + propi
IPBC
Si-Quat
IPBC + propi
water-based
solvent-based
+ DMS/n-OTES water-based
+ MTM/n-OTES solvent-based


dE
60
50
40
30
20
10
0
DMS/n-OTES 1
DMS/n-OTES 2
PDMS
PDMS/TES
n-OTES
MTM/n-OTES
IPBC
Si-Quat
IPBC + propi
IPBC
Si-Quat
IPBC + propi
Control
water-based
solvent-based
+ DMS/n-OTES water-based
+ MTM/n-OTES solvent-based


dE
60
50
40
30
20
10
DMSn-OTES 1
DMSn-OTES 2
PDMS
PDMSTES
n-OTES
MTMn-OTES
IPBC
Si-Quat
IPBC + propi
IPBC
Si-Quat
IPBC + propi
Control
water-based
solvent-based
+ DMSn-OTES
water-based
+ MTMn-OTES
solvent-based


dE
60
50
40
30
20
10
0
DMS/n-OTES 1
DMS/n-OTES 2
PDMS
PDMS/TES
n-OTES
MTM/n-OTES
IPBC
Si-Quat
IPBC + propi
IPBC
Si-Quat
IPBC + propi
Control
water-based
solvent-based
+ DMS/n-OTES water-based
+ MTM/n-OTES solvent-based